3D Printing vs. CNC machining

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Learn about the expectations, limitations and differences when getting a part made with 3D printing compared to CNC machining along with a series of case studies covering real world examples.

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Introduction

Computer numerical control (CNC) machining is a common subtractive manufacturing technology. Unlike additive manufacturing, CNC machining typically begins with a solid block and uses sharp rotating tools or cutters to remove material to achieve a final shape. CNC is one of the most popular method of traditional machining for both small one off jobbing and high volume production offering excellent repeatability, high accuracy and a range of tooling options for a number of machining applications, geometries and materials.

This article will present the main differences between additive manufacturing (AM or 3D printing) and CNC machining and includes a series of case studies to allow a designer to assess when to use CNC or AM.

Comparison of properties

The following table compares the main manufacturing properties to be considered when making a part by CNC machining or 3D printing.

Property	CNC	3D printing
Material	Mainly used for machining metals. Can also be used for machining softwoods and hardwoods, thermoplastics, acrylic, modeling foams and machining wax. Requires different cutting tools for each material.	Predominately polymeric plastics with some technologies able to produce parts from metals, ceramics, wax, sand and composites.
Speed	CNC machines are able to remove material at a much faster rate than AM is able to build it. They generally require a significant amount of process planning and setup, particularly when multiple machining steps are needed. Parts often require repositioning or relocation.	Can produce a part in single step meaning there is no dependence upon other manufacturing stages other than post processing. Also offers batch manufacturing for several process (most notably SLS and metal printing).
Complexity	Undercuts, tool access, internal features and clearances are all limitations that must be considered. A sound understanding of the machining process, the order a part will be manufactured and part orientation is required.	Complex designs can be produced using AM in a single step with very little process planning. Understanding how to correctly orientate a part, feature size restrictions and physical build size are generally the main limitations.
Accuracy	Accuracy is defined by the tool geometry. Because all tools are rotated, internal corners at machined with a radius. Features smaller than the tool size can be produced resulting in walls with a thickness smaller than the tool diameter. Provides superior surface quality when compared to the best outputs 3D printers can produce.	Minimum feature size is usually governed by the diameter of the material delivery mechanism (e.g. the nozzle for FDM or jets for material jetting) or the diameter of the energy transferring component of the machine (e.g. sintering lazer or UV light source). FDM printers produce parts with a layer height of 100 - 200 microns while material jetting printers can print at resolutions as low as 16 microns.
Geometry	CNC machines rely upon a point to point machining process following a predetermined tool path to remove material. There are therefore restrictions on the surfaces a CNC machine can reach without needing to manipulate a part. Can be used to machine very large and very small parts.	Features that are not connected to the model or have nothing below to brace them require extra support material to be printed. This increases the cost and time to complete a print.
Programming	Requires an expert operator or engineer to consider tool selection, spindle speed, approach position and angle and cutting path. These factors all greatly impacting the final part quality and build time.	Once a model has been uploaded and the orientation, layer height and support locations are selected most AM machines can produce a complete part without any human intervention.

Case Study 1 - A simple enclosure

A simple aluminium CNC enclosure (left) and an FDM electronic enclosure (right)

The use of CNC for the manufacture of enclosures is typically driven by the need for customisation (either to fit a specific product or for a one off job). CNC machines are able to rapidly remove material but require setup time and planning to produce the optimal part. The final quality of the CNC enclosure depends highly on the skill of the operator. CNC is capable of producing higher tolerances than FDM allowing components to sit perfectly in place. A range of materials can be used including metals and plastics.

FDM is the most cost effective and popular 3D printing technology. The low cost of print material (approximately $25 - $30 per kg), quick lead time and ease of use mean it has seen rapid growth in the hobbyist and prototyping industry. This makes it ideal for designing enclosures where several iterations may be required to achieve perfect fit. FDM has relatively low dimensional accuracy when compared to CNC machining however is perfect for prototyping where form or fit are more important than function. The additive nature of the FDM process means that layer lines are often visible. FDM is only able to produce parts from thermoplastics.

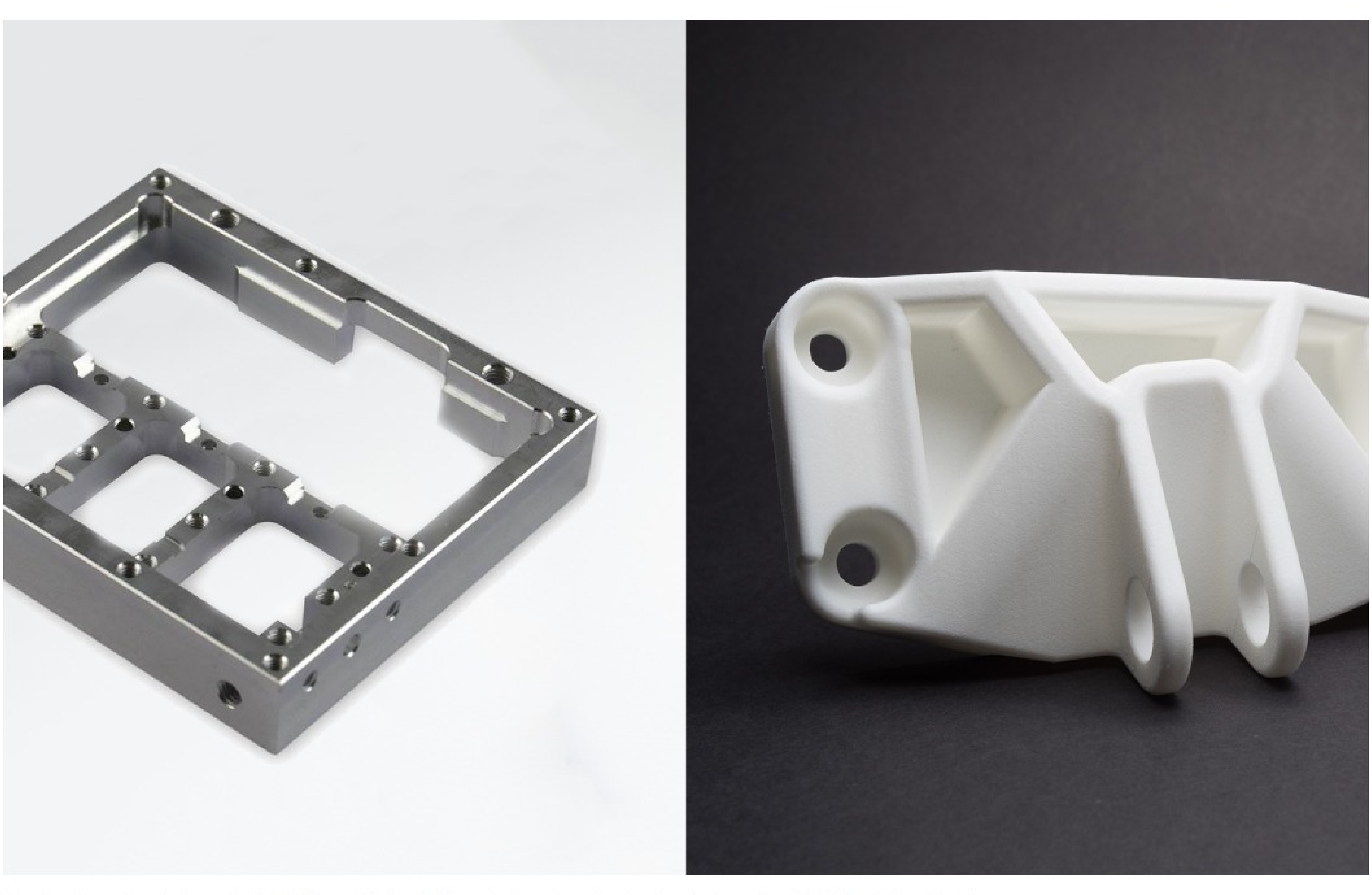
Manufacturing requirements

- Clearance for internal components
- Method for securing lid (threaded holes, snap fits etc)
- Tolerances not critical
- One off production

Summary

Property	CNC	3D printing
Cost	$$	$
Material	Aluminium alloy	ABS/PLA
Speed	Long setup time but very quick material removal stage.	Approximately 3 - 8 hour depending on size and complexity.
Accuracy	Within 0.05 mm	Within 1 mm
Surface finish	Excellent when tool speed, cut depth and tool geometry are optimised.	Not smooth, print lines will be visible. Post processing to a smooth shiny surface is possible.

Case Study 2 - A functional bracket



An aluminium bracket made via CNC machining (left) and a functional nylon bracket made with SLS printing (right)

CNC machining is ideal for producing geometries from materials where welding or assembly may be difficult or affect performance. Brackets are a common part produced via CNC machining as this method of manufacture allows for high repeatability, excellent accuracy (making it ideal for critical features like center-to-center hole dimensions) and very good surface finish. The cost of CNC is dependent upon the material, machining time and operator costs. A strong, lightweight and stiff material that is easy to machine is required resulting in aluminium or titanium often being used, increasing the cost compared to an equivalent steel bracket. CAM design is needed to optimise tool path.

SLS is often used to produce functional nylon parts. Parts have a high level of accuracy (as the material is sintered by a laser) and the process can easily print hollow sections, overhangs and undercuts. The high tear resistance of SLS nylon and excellent strength to weight ratio mean it is an ideal material for bracket manufacture. Depending on size, a low production run of brackets can be made in a single print (with an standard build volume of 300 mm x 300 mm x 300 mm). SLS does not require parts to be reorientated, only uses the material needed to create a part (reducing waste) and requires little post processing other than removing the parts from the powder and cleaning with compressed air. The cost of raw SLS nylon powder is typically around $50 - $60 per kg.

Manufacturing requirements

- Light stiff material
- Accurate centre-to-centre hole dimensions for mounting
- Ribs and fillets to reduce stress concentrations and aid with handling
- Mid volume production (less than 20)

Summary

Property	CNC	3D printing
Cost	$$$$	$$$
Material	Aluminium alloy	Nylon 12 powder
Speed	CAM design needed. Tool path and material removal order critical to production speed and part quality. Generally 2 - 3 parts can be machined at a once based on machine bed size.	No design optimization for process needed. SLS parts are often printed in batches taking around 20 - 24 hours to print all parts in the batch. Parts then need to cool before handling.
Accuracy	Within 0.005 mm	Within 0.1 mm (some shrinkage occurs but this is generally compensated for in the design)
Surface finish	Excellent when tool speed, cut depth and tool geometry are optimised.	Rough, matte, porous surface.

Case Study 3 - A complex metal turbine

5-axis CNC machines are used to create very complex components from a solid block of material. The machines are able to remove material at a rapid rate however the extensive CAM work needed beforehand increases lead time and cost. 5-axis CNC require highly skilled designers to program the machine and optimise all machine parameters. They often switch tools multiple times during the machining process to improve surface finish and dimensional accuracy. This also allows the 5-axis CNC machines to machine a large range of materials.

DMLS uses metal powder to produce complex metal parts. By selectively melting the powder one layer at a time, DMLS is able to achieve a high level of accuracy and detail. The surface produced is very smooth (lower quality than CNC machining) and parts can be sanded and polished to a mirror finish. The nature of manufacturing with powder results in parts with excellent mechanical properties and a high level of homogeneity Because of the high temperatures involved in the DMLS process distortion and warping can be an issue so parts are securely attached to the print bed, have a large amount of support attached to them and are heat treated to reduce residual stresses after printing. Depending on size, parts can also be printed in batches and from a limited range of metals.

Manufacturing requirements

- High accuracy essential
- Good surface finish critical to performance
- Strong, lightweight material
- Low volume production (less than 5)

Summary

Property	CNC	3D printing
Cost	$$$$$	$$$$$
Material	Aluminium alloy	Aluminium powder
Speed	Significant CAM design needed to optimise machining process. Once optimized part production is relatively quick.	Parts can be printed individually or in batches. Slow build speed but no tooling or operator intervention is needed.
Accuracy	Within 0.001 mm	Within 0.05 mm. Warping and distortion can be an issue if not designed for correctly.
Surface finish	Excellent when tool speed, cut depth and tool geometry are optimised.	Excellent surface finish that can be sanded and polished.

Conclusions

AM is best suited for complex and intricate design as well as the production of prototypes for fit and form justification. The range of materials parts can be produced with is more limited than CNC machining and often surface finish and dimensional accuracy is not as good as what can be achieved by a CNC machine. A number of 3D printing technologies offer batch manufacturing.

CNC machines are ideal for simple geometric designs made from traditional materials that require high precision and surface finish. The need for expert CAM design as parts become more complex can increase cost and lead time. CNC machines often require more human input than 3D printers with the quality and speed a part is produced at depending heavily on the operator.

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